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Sector field deflection system, in particular for a low-voltage electron microscope

A sector field deflection system, in particular for a low-voltage electron microscope, has an outer pole shoe (12) which can be excited uniformly and surrounds two or more identical inner pole shoes (20, 22, 24), which can likewise be excited and whose excitation differs from the excitation of the outer pole shoe and provides stigmatic double focusing.

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Description

The invention relates a sector field deflection system having three or more magnet sectors and shoes, in particular for a low-voltage electromicroscope, which uses elastic or inelastically scattered electrons or ions for imaging. It is also suitable for specific forms of deflection devices for studying particle characteristics. A low-voltage electron microscope in which the invention can be used was specified by E. Bauer in 1962. A spectrometer for which the new sector field deflection system is suitable is of the Castaing-Henery type.

Low-voltage electron microscopes (low-energy electron microscopes (LEEM), illuminate the surface to be examined with parallel electron beams which are collimated by means of an objective lens, in particular an objective cathode lens, which is aligned such that its axis is at right angles to the sample to be examined. Electrons which are reflected along the illumination axis are accelerated and focused again, and are used to produce a map of the structure, topology and/or of the chemical characteristics of the observed surface. Electron microscopes such as these have a so-called magnetic sector deflection unit (separator), which allows an illumination beam to be introduced on one side of the deflection unit and to be deflected onto the axis of the objective lens or cathode lens. The reflected deflection beam runs along the same axis of the cathode lens, but owing to the fact that the electron velocity has been reversed, is deflected in the deflection unit away from the illumination axis into the axis of an imaging system with amplification lens or the like, which produces the image of the observed surface. One essential feature of this deflection system is that the optical units which are used for illumination and imaging may be physically

separate, thus avoiding an otherwise insoluble problem of illumination and imaging.

For optimum operation, the deflection unit should have various specific characteristics. If all the lens systems are fixed, it is necessary to ensure that the center axis of both the illumination beam path and of the imaging beam path follow specific accurately defined paths outside the area of the sector deflection unit, in this way ensuring that the two beams enter and emerge from the objective lens of the optics along the same axis into the deflection unit. The deflection system also has to produce a focused image of the electron beam source on a point immediately above the objective cathode lens, and it must also pass through a focused image to a schematically arranged point along the imaging beam path. In order to avoid distortion and astigmatism, it is also desirable for the sector field deflection system to be stigmatic or birefrigent. This means that it focuses a point above the objective at another point outside the deflection unit, irrespective of whether the electrons are moving along the horizontal or vertical plane of the pole shoes on the magnetic deflection unit. Furthermore, the sector deflection unit should be able to satisfy the requirements mentioned above even when the illumination beam and the imaging beam have different energies. This last-mentioned characteristic is important in particular when inelastic electrons, namely those which lose energy to the sample to be examined, are used for imaging.

Until now, sector deflection units have comprised a single fixed pole shoe, which is shaped such that the desired deflection is achieved. The radius of curvature of the deflected beams and their inclination to the boundary edges of the magnet sectors determine the

characteristics of the sector deflection unit. Embodiments are also known in which cut-out areas are provided in a single pole shoe in order to achieve the desired beam path. In order to ensure symmetry between the incident illumination beam and the emerging imaging beam, all three outer edges must be at right angles to the beam axes outside the deflection unit, while the inner surfaces of an individual pole shoe may in principle by formed such that a symmetrical, stigmatic image is produced. Independently of how the known deflection units can be advantageously operated, it must not be forgotten that such integral pole shoe configurations in principle are not able to cope with a large number of different imaging beam energy levels, while only one illumination beam with a single specific energy can be used. One beam or the other must be at a distance from the desired intrinsically defined beam path axis since different energy levels lead to different radii of curvature in the same magnetic field. Although it is theoretically possible to use a range of appropriately shaped deflection units with two or more axes of symmetry in order to achieve the desired stigmatic and non-dispersive imaging response, deflection systems such as these would be extraordinarily complicated. Systems such as these with symmetrically curved incident and output axes belong to the prior art.

The invention is based on the object of providing a sector field deflection system such that the abovementioned requirements which are placed on it are satisfied with a comparatively simple design and, even in the case of inelastically scattered electrons or illumination and imaging beams with different energy levels, they nevertheless produce a stigmatic double-focusing effect. Finally, it should be possible to

operate the deflection system both with elastic and with inelastically scattered electrons or ions.

A sector field deflection system which achieves this object is characterized with the refinements in the pattern claims and will be explained in more detail with reference to an exemplary embodiment.

The sector field deflection system according to the invention has a uniformly excited outer pole shoe, which surrounds two or more identical symmetrically arranged inner pole shoes which are excited by a field which is not the same as the outer excitation field, and produces stigmatic double focusing. The deflection unit uses elastic or inelastic scattered electrons or ions for imaging. The outer pole shoe or the outer pole piece is excited uniformly.

One refinement of the invention provides for the capability for at least one of the pole shoes to be excited differently to the others, in order to produce illumination and imaging beams which are in mirror-image form outside the deflection system, even when the illumination beam and the imaging beam have different energy levels.

In another refinement of the sector field deflection system according to the invention, one inner pole shoe can be excited with a different intensity to the other inner pole shoes. However, it is also possible to provide an additional coil on one inner pole shoe which, when excited, produces a field component in the opposite direction. In both cases, this leads to quadrupole focusing along a single axis or along both axes.

One exemplary embodiment of the invention will be explained in more detail with reference to a drawing which shows a cross section through a sector field deflection unit.

A sector field deflection system 10 comprises a triangular outer pole shoe 12 with a central triangular aperture opening and, arranged symmetrically in this opening - according to the invention - three inner identically shaped pole shoes 20, 22 and 24, which are separated from the outer pole shoe by an air gap 26 and produce a deflection angle of 60°. The outer triangular pole shoe 12 thus surrounds both the inner pole pieces 20, 22, 24 and the triple-symmetrical arrangement of the inner pole shoes, which has a triangular cross section. The outer pole shoe 12 acts by means of a uniform magnetic field on the illumination beam segments AI and AO and on the imaging beam path segments BO and BM. The beam segments AI and BM have to pass along the same mirror-image symmetrical beam path, with the beam segments AO and BO are superimposed outside the deflection system 10. The inner pole shoes 20, 22 and 24 have identical shapes, so that they match one another within the outer pole piece 12. The inner edges are aligned such that they are aligned along each beam axis. The inner and outer images of the outer pole shoe 12 run parallel to one another and at right angles to the external beam axis. However, this is not a necessary arrangement for the inner edges of the inner pole shoes 20, 22 and 24. The latter can be excited independently from one another by means of separate excitation coils in order to produce any desired fields along a [lacuna] at right angles to an axis which is at right angles to the plane of the drawing. It is assumed that mutually facing pole piece pairs which determine the deflection gap of the inner pole pieces can be excited with a small component of a field in the

opposite direction, so that a weak quadrupole lens can also be formed. These quadrupole components are used for correction of resident astigmatism, to be precise separately for the illumination beam and for the imaging beam.

The following embodiment illustrates that it is possible to make the system double-focusing or stigmatic even if the exact characteristics cannot be calculated in advance. The literature shows that the focusing characteristics of any sector deflection unit depend on the radius of curvature of the beam (excitation) and the inclination of the beam axis a1 and aM to the boundary of each sector on entering and emerging from the sector. If only the outer pole piece 12 is excited and its inner and outer edges run parallel to one another, then it is stated in the literature that the system of electron beams which run outside the axis is focused in the vertical direction and not in the horizontal direction (fraction). However, if only the inner pole shoes are all excited in the same way, all of the central beams enter and emerge at right angles to the active pole shoe boundaries. The literature states that the system will then be focused in the horizontal plane but not in the vertical plane. In both cases, the beam paths of the electron beams AI, AO, BO, BI which run along the axis run identically to one another even if they depend on which pole shoe is excited. If both the outer pole shoe 12 and the inner pole shoes 20, 22, 24 are excited, focusing takes place both in the horizontal plane and in the vertical plane, and the symmetry of the beam path segments is ensured. It follows from this that stigmatic focusing can be achieved. If an object point FI is arranged correctly, its conjugate image points FO and FM are imaged schematically with a magnification factor of minus 1(-1). In other words, differential

excitation of the inner pole shoes and of the outer pole shoe has the effect of a change to the effective focusing strength of the inner pole shoe boundaries, such that focusing is ensured. Owing to the internal symmetry of the illumination beam and of the imaging beam, this ensures that the points which are free of chromatic aberration are located in the center of the system, namely where the sample is imaged.

From what has been stated above, it is evident that the magnetic sector field deflection system 10 in principle has a double-focusing effect for a single nominal beam energy level. However, if the energy in the imaging beam AI-AO is not the same as that of the illumination beam BO-BM, it is possible, for example, for the inner pole shoe 22 to be excited somewhat differently in order to force it back to the desired output access. While the shape of the beam path changes (for relatively low energies it is curved to a greater extent than the outer pole piece, and for correspondingly straighter energies, in the inner pole shoe), the symmetry of the beam paths BO to BM ensures that it emerges along the imaging access. It can be shown that the imaging conditions change somewhat and slight astigmatism occurs, since the ratio of the inner excitation to the outer excitation is different. This discrepancy can be corrected by means of the built-in, previously mentioned quadrupole arrangement. For small energy differences, the effect on the image astigmatism is negligible, provided that it is located at the achromatic points.

The arrangement may have triple, quadruple or quintuple symmetry.

In one practical exemplary embodiment of the sector field deflection system according to the invention, the

outer edge length of the outer triangular pole shoe 12 was 150 mm, the field strength of the pole shoes was 100 ampere turns (Gauss) for each pole shoe, the focal length (distance between the image points FI and FM) from the center point 200 mm, and FI was symmetrical with respect to FM.

If the excitation of the illumination beam BO-BM and of the imaging beam AI-AO is different, the field strength changes in proportion to the square root of the energy difference. For this purpose, the excitation current level may differ, or an additional coil may be provided on one pole shoe. The focal length changes only slightly when the excitation differences are small. Slight astigmatism may occur.

The 4-magnet embodiment which is illustrated in the drawing (the magnets are predominantly electromagnets, although permanent magnets may also be used) jointly produce two fields in opposite directions, which form a saddle in the center of the field strength distribution.
The magnets are composed of iron of high permeability and low remanence. The dimensions of the outer pole shoe may be from about 75 to 150 mm. A power supply unit with a regulated current is used for the power supply.

Patent Claims

1. A sector field deflection system having three or more magnet sectors and shoes, in particular for a low-voltage electromicroscope, which uses elastic or inelastically scattered electrons or ions for imaging, distinguished by a uniformly excited outer pole shoe (12) which surrounds two or more identical inner pole shoes (20, 22, 24), which are likewise excited and whose excitation differs from the outer excitation and provides stigmatic double focusing.

2. The sector field deflection system as claimed in claim 1, wherein at least one of the pole shoes can be excited differently to the other pole shoes, such that the illumination beam and the imaging beam run in mirror-image form outside the deflection system, even if the energy in the illumination beam is not the same as the energy in the imaging beam.

3. The sector field deflection system as claimed in claim 1, distinguished by an inner pole shoe which can be excited differently to the other inner pole shoes, or by an additional magnet coil on one of the inner pole shoes, which produces a field component which is in the opposite direction and leads to quadrupole focusing on one of the axes or both axes.

4. The sector field deflection system as claimed in one of claims 1 to 3, wherein the outer pole shoe (12) is in the form of an equalateral triangle, and surrounds to the inner pole shoes (20, 22, 24) leaving free a gap (26), forming a symmetrical arrangement.

One page of drawings attached

DRAWINGS PAGE 1

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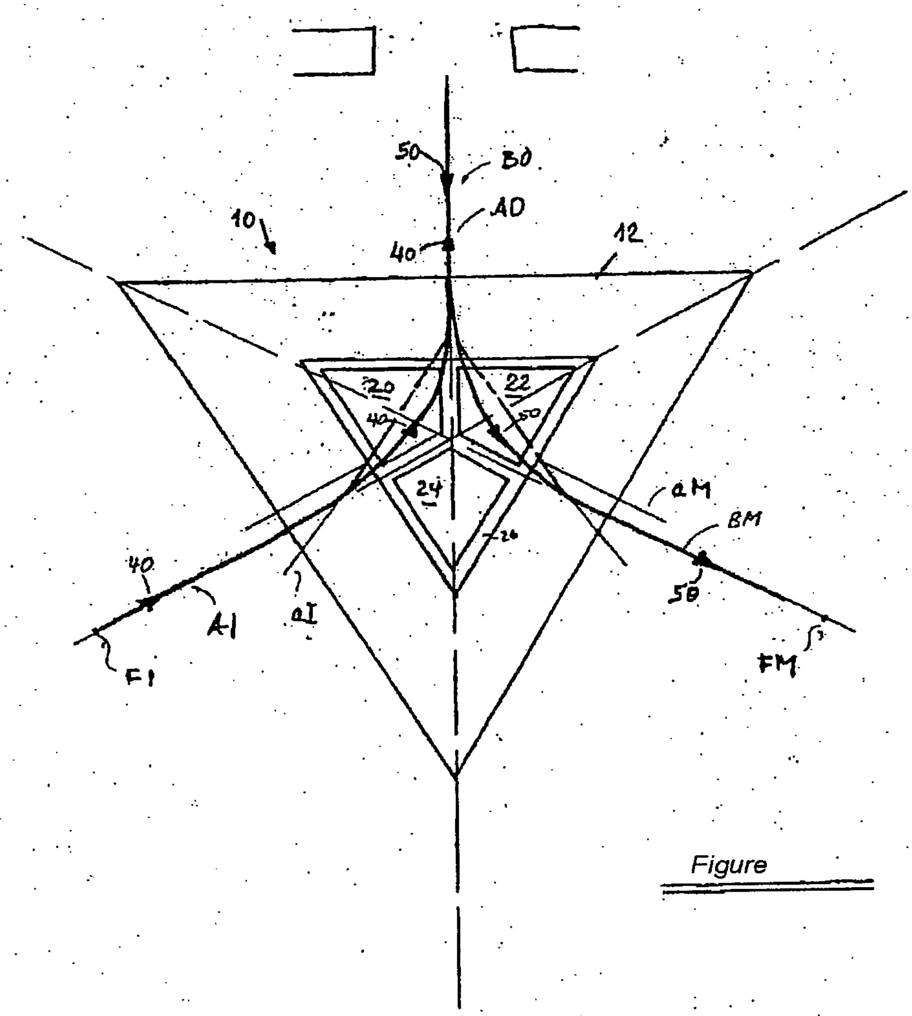

Figure